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A NOTE ON THE AUTOMATIC GENERATION AND RECOGNITION OF TEXTURES

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SUMMARY

A simple algorithm for generating abstract textures by computer has been developed, wherein the visual appearance of a pure texture is produced by controlling the shape, color, and intersection properties of its component parts. The pure texture is subsequently transformed by superimposing noise, or by averaging adjacent points, or by accentuating boundaries. Textures were printed out by machine using a character set which reasonably approximates eight equally separated gray levels when viewed as a gray wedge. A set of discriminators computed from the textures was used to analyze how well a pattern recognition scheme might be able to identify the various transformed versions of a given pure texture. Various entropy measures, as well as several indices computed from the two-dimensional power spectrum, proved useful for this purpose. These preliminary results suggest that automatic pattern recognition techniques, utilizing discriminators especially designed to characterize textures, may prove to be a powerful tool for spaceborne imagery processing. However, a major research effort would be required to develop this approach.

INTRODUCTION

The various probes sent to planets, such as Mars, transmit large quantities of information. The bandwidth limitations, resulting from the combination of great distance and on-board power constraints, make it desirable to compress this information prior to transmission and later to regenerate it back to earth. In particular, it is most desirable to compress pictures, since they involve an extremely large amount of information (on the order of 10^7 bits each). Ideally, one would characterize a scene by a number of parameters which would allow a reconstruction that, to the human visual system, resembles the original scene. A particular example of such compression and parameterization would be to divide the scene into areas of uniform texture, and then to transmit a representation of the boundaries of each area together with the parameters of its texture. The scene would be reconstructed by depositing the various boundaries and generating the appropriate textures within each boundary.

This paper presents the results of preliminary experiments in which a simple generator produced textures, and an independent set of discriminators, computed from these textures, classified them. These studies suggest that differences in texture, produced in a controlled way by the texture generatore, are detectable by the discriminators. The classification of these textures by humans has not yet been undertaken.

THE TEXTURE GENERATOR

We construct a texture by depositing a variety of splotches, each having a constant gray tone, on the image-plane where the texture is to be constructed. We control the characteristics of each splotch and the total number of splotches of each class appearing in the final texture. The controllable characteristics of individual splotches are:

Shape	- consists of parameters of length, width, and direction.
Shade	- controls which of 8 gray levels the splotch displays.
Overlap Priority	- controls which of 2 intersecting splotches is on top, and therefore is visible.

A splotch class is defined by specifying the following parameters:

Length Width Direction Shading	Characteristics common to all splotches in the class.
Priority Mean Priority Variance	Individual splotches in the class may have different values. The priority of any particular splotch is a random number chosen from a distribution with the specified mean and variance. The splotch having the highest assigned number (the highest priority) is displayed.
Density	Number of splotches appearing per image.

Note on the particulars of splotch generation: The method of splotch generation actually used imposes severe constraints on the type of splotch that can be generated. There are only four allowed orientations, and each splotch is produced by the following procedure (See Figure 1): Take a square at position 'a' and slide it in any of the four principal directions to final position 'b'. The splotch then consists of all the area covered by

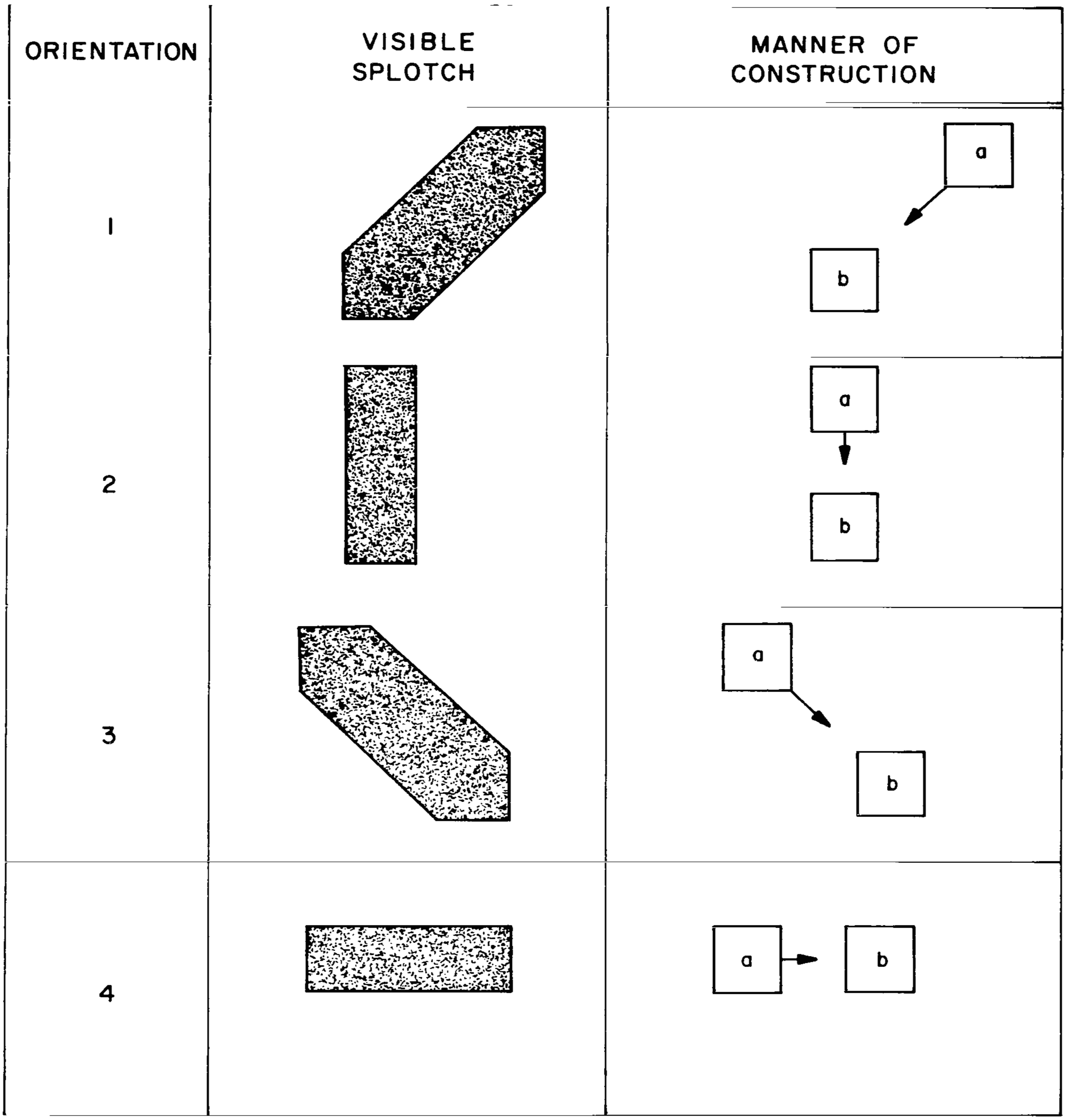


Figure 1.- Splotch orientations

the initial and final positions plus the area swept in between. The control parameters are direction, size of the original square, and distance that this square is moved. (These parameters are related to the ones previously defined as follows: Width = square size, Length = square size + sweep length).

A texture is generated by defining various classes of splotches and then depositing them on the image-plane according to the appropriate densities. After this construction of an initial or "pure" texture, a variety of other textures can be constructed by applying a variety of transformations to it.

Consider the following example, consisting of an initial texture and several transformations. The initial texture was constructed from eight splotch classes which were identical except for shade. The texture therefore consists of a set of overlapping identical shapes with various gray levels distributed among them (Figure 2a). The class parameters (excluding brightness) were:

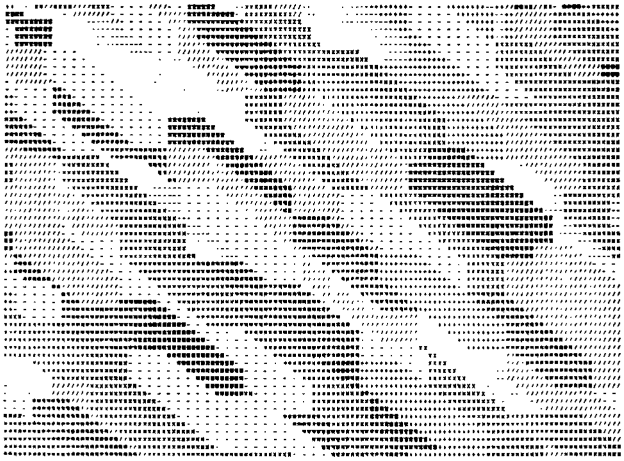
Length	= 13
Width	= 4
Direction	= 3 (upper-left to lower-right)
Priority mean	= 1000
variance	= 200
Density	= 30 elements of each class per picture (not all can be seen due to overlapping)

Figure 2b is a noisy version of Figure 2a. It was constructed by randomly changing the gray value of a point by 0, 1, or 2 units. The particular probabilities of change were

Amount of Change	Probability
-2	4%
-1	41%
0	10%
+1	41%
+2	4%

Figure 2c is a smeared version of Figure 2a. Each point of Figure 2a was replaced by the average of all points in a 3 x 3 neighborhood centered at that point. The principal effect of averaging is to soften sharp points and edges. This softening produces a much more realistic looking texture than the initial textures of 2a.

Figures 2d and 2e each represent a double transformation wherein a "halo" operation was performed on the smeared texture of Figure 2c. Haloing consists of emphasizing the darkest and lightest areas of the picture by putting a ring of different



a. ORIGINAL

d. LOW HALO, D-GRAY = 3

b. NOISE

e. HIGH HALO, D-GRAY = 5

c. SMEAR

Figure 2.- Texture with identical shapes

shade around them. This ring is characterized by a difference of gray value, D-gray, such that the brightness of the ring equals the brightness of the area ± D-gray, (use "+" for low valued (dark) areas and "-" for high valued (light areas)). In Figure 2e, D-gray equals 5. This produces a very well defined ring which causes a foreground-background effect with the ringed areas looking like well-defined objects on a smeared background.

In Figure 2d, D-gray = 3. This produces a more subtle effect wherein the ringed areas are not so easily perceived as such, but where they nevertheless look more definitively colored than the same areas in the original smeared picture, Figure 2c. Haloing makes the blacks look blacker and the whites whiter even though the areas of extreme black and white are exactly the same shade in pictures of Figures 2c, 2d, and 2e.

Another series of textures is depicted in Figures 3a to 3f. Here, one parameter (length) was gradually increased from 4 to 13, producing a sequence of textures varying from completely non-directional to highly directional. The fixed parameters common to all the textures were:

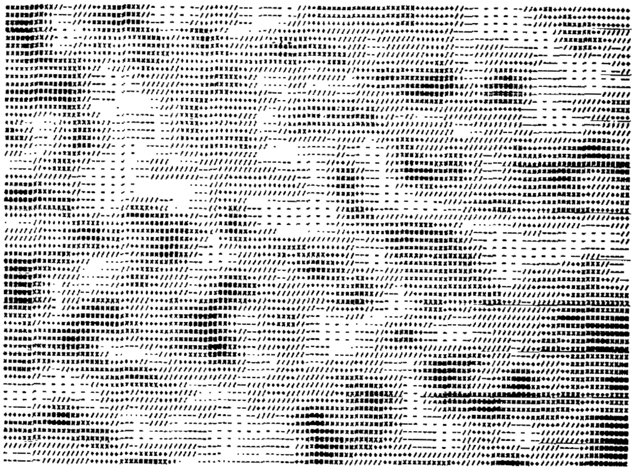
8 classes, 1 of each brightness	
Width	= 4
Orientation	= 3 (upper left to lower right)
Priority mean	= 1000
variance	= 200
Density	= 40 elements per class per picture

After production of the original textures (not shown) all textures were smeared to produce the results seen in Figures 3a - 3f.

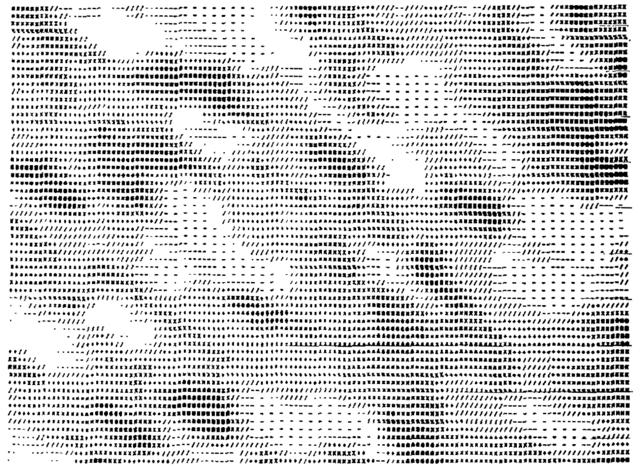
The length parameters vary as follows:

Texture	Length
3a	4
3b	5
3c	6
3d	8
3e	10
3f	13

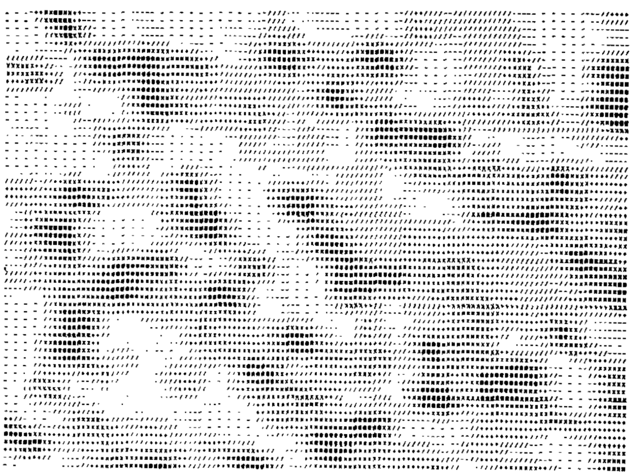
Appendix A contains a discussion of a generator for arbitrary textures and Appendix B contains a discussion of raster scan generation of textures.



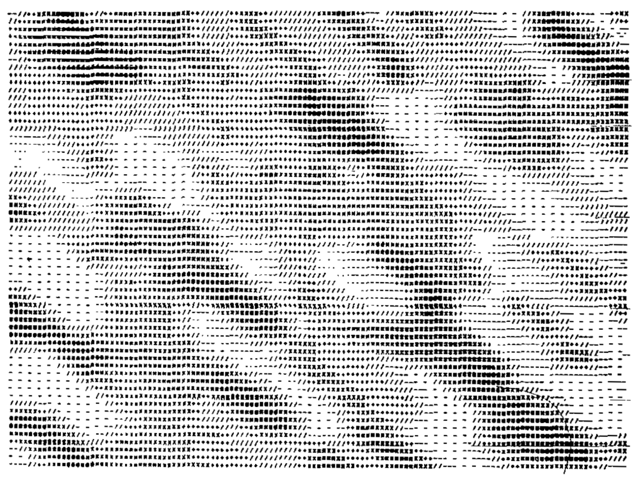
a. LENGTH = 4



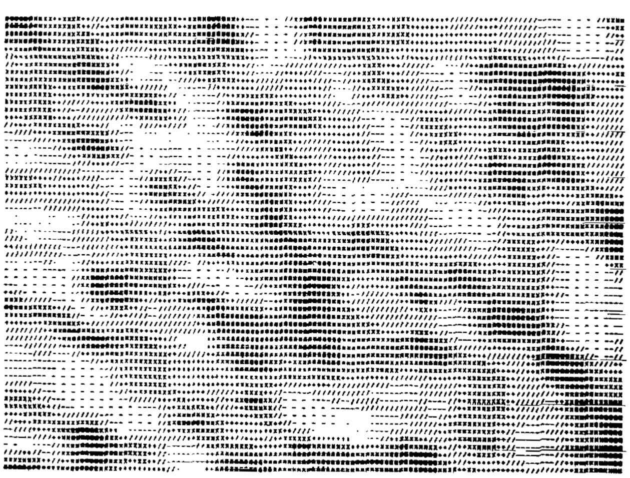
d. LENGTH = 8



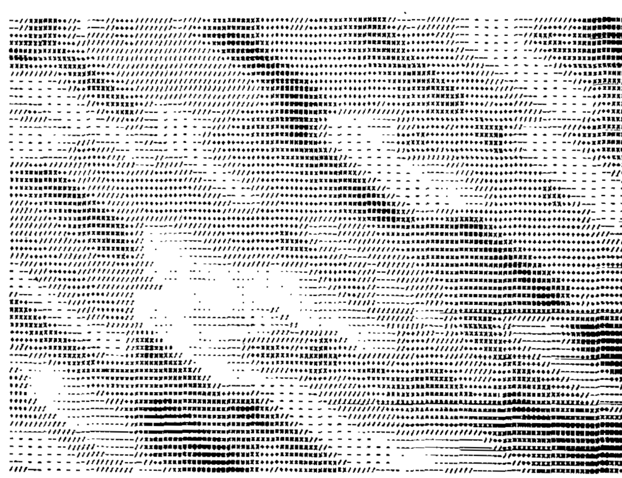
b. LENGTH = 5



e. LENGTH = 10



c. LENGTH = 6



f. LENGTH = 13

Figure 3.- Texture with increasing shape length

DISCUSSION OF DISCRIMINATORS

A set of discriminators devised by Eugene M. Darling Jr. (Ref. 1) of NASA Electronics Research Center were computed from the textures shown in the previous section. These discriminators have performed well on recognition problems involving cloud patterns and lunar terrain formations. The following discriminators from that set have proved useful for the present texture recognition problem:

(1) Variance of intensity - consider the picture as a collection of points with intensity values from 0 to 7. This discriminator measures the variance of the brightness values over this collection.

(2) Gray Area - Mean and Variance - Imagine the picture as a collection of irregularly shaped patches of uniform intensity. This discriminator pair measures the mean patch area over the picture and the variance in patch area.

(3) Information X, Information Y - This discriminator measures the average pairwise information between all adjacent element pairs in the chosen direction.

(4) D^2x, D^2y - These discriminators measure the information in the x and y directions over the field of second derivatives in the x direction. The second derivative of a point is computed as follows: let b_p = brightness at point p, b_{p-1} and b_{p+1} be the brightnesses of the points to the left and right of p respectively. Then

$$D^2 \text{ at point } p = \frac{(b_{p+1} - b_p) - (b_p - b_{p-1})}{2}$$

$$= \frac{b_{p+1} + b_{p-1}}{2} - b_p$$

The information over this second derivative field is then computed as in the above information discriminators.

The final discriminators are computed from the two dimensional power spectrum of the picture. They involve measures of the mean spectral density in various portions of the frequency plane.

(5) Rings 1 - 9 - The ring parameters slice nine successive annuli out of the frequency plane (Figure 4a). The relative weights of the rings roughly indicate the periodicities appearing in the picture - the inner rings indicate low frequencies, and the outer rings indicate high frequencies.

(6) Ray Ratio - Imagine that the frequency plane is now sliced in a pie-slice manner (Figure 4b). The ratio of the heaviest slice to the lightest slice is called the Ray ratio. It measures the tendency of the picture to be highly directional in some direction. A ray ratio of 1 would indicate a non-directional texture.

DISCRIMINATOR RESPONSE TO A SET OF GENERATED TEXTURES

The aforementioned discriminators were computed for a set of textures constructed as follows: Two classes of initial, undistorted textures were selected, and a variety of transformations were performed on each class. The goal was to see how well the discriminators could determine which transformation had been performed when the original undistorted class was unknown.

The two original classes consisted of the textures in Figures 3a and 3f; that is, all parameters were the same in the two classes except for length. The transformations were smear, noise, and a haloed smear.

The following is a list of the discriminators which best separated the given class from all other classes:

(1) Pure Textures vs. All Others.

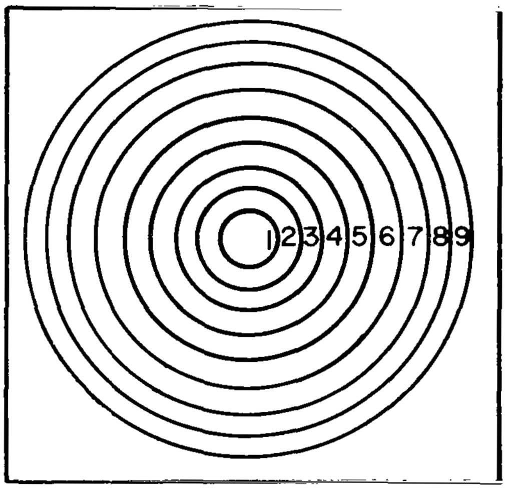
(a) Mean gray area - This discriminator was consistently higher for the pure textures than for any of the others. This is due to the uniformity of shade over the splotches used in producing the pure textures.

(b) Information x, y - This discriminator was generally lower in the undistorted classes. This is again due to the large areas of uniform brightness representing the generation splotches.

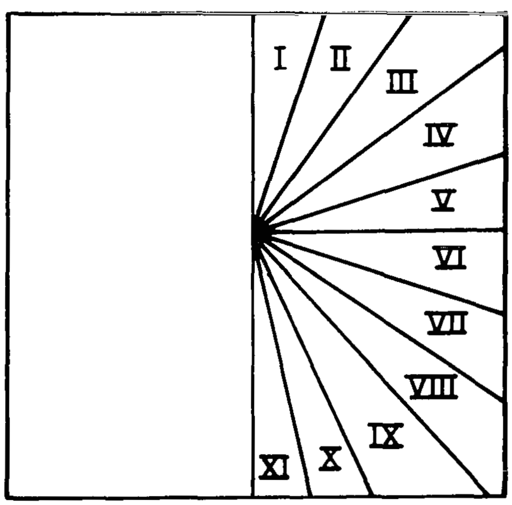
(c) D^2x, D^2y - This discriminator was higher in the undistorted splotches. This is due to the sharp edges between one splotch and another. (The author can find no good reason,however, why the noisy transformation doesn't produce even higher D^2x and D^2y values.)

(2) Smear vs. All Others.

(a) Rings 7 to 9 were decidedly lower than in the other classes. This is due to the fact that smearing eliminates virtually all of the high frequency content of the picture.



A. RINGS



B. RAYS

Figure 4.- Discriminators computed from the two dimensional power spectrum

(3) Noise vs. All Others.

(a) Information x, y was <u>higher</u> for the noisy class than for other classes. This is due to the perturbations introduced by the noise transformation.

(4) Halo vs. All Others.

(a) Rings 7 to 9 were <u>higher</u> than in other classes. This is due to the high frequencies introduced by the high contrast, unit-thick halos.

The above results are derived from only a small experimental set of textures. Firm conclusions on the abilities of the current discriminators must await further experimentation. All that can be said now is that the discriminators are responsive to a variety of textures, and seem able to recognize some basic similarities (i.e., which transformation type was used) across a few different classes of textures (i.e., textures of different lengths but otherwise similar).

Ideally the discriminators should be able to recognize similarities between two textures irrespective of the variety and range of those texture components which are not similar. However, the present experiment only shows that the discriminators can recognize four different similarity classes (the pure texture and three transformations) over one varying component (length).

POSSIBLE IMPROVEMENTS OF THE TEXTURE GENERATOR

The current texture generation procedures can be criticized on a number of grounds. For example, a variety of difficulties arise from the fact that only four directions are allowed:

(1) It is impossible to produce smoothly curved splotches. Splotches can consist only of straight edges and sharp corner points. Both of these effects are irritating and generally force one to use a smear transformation to soften the texture.

(2) The texture exhibits an excess of parallelism. This can be seen especially clearly in Figure 2f. In general, one would like to display splotches with a <u>tendency</u> toward some direction, combined with a graded degree of this tendency, rather than the present all or nothing tendency towards each of the four directions.

Another problem of the current generator is that of joined edges. Two adjacent splotches having the same shading will appear as one large splotch. This is contrary to real textures where we would expect some sort of edge effect due primarily to shadows and depth effects. Real objects would have thickness and, although adjacent objects might be of the same shade, they would probably not be exactly the same height. This height difference would cause an edge effect.

Another type of difficulty with the current batch of textures arose out of the author's failure to observe what he chooses to call "the principle of associated qualities". This principle is nothing more than the observation that each of the basic elements of a texture will consist of an associated set of qualities; a particular shape of splotch is likely to be associated with a particular size and coloration. Knowing some of the qualities of a splotch, one should be able to reliably predict many other qualities. Such groupings of associated qualities are probably the primary features that influence how the eye decomposes and analyzes a texture.

The current textures violate this principle, because each splotch shape can have any of the possible brightness levels. This procedure specifically divorces any particular shade from association with any specified shape. Since shade is one of the primary characteristics that would be associated with a shape, the current textures are probably significantly different in visual effect from "real" textures.

Another fault is the tendency of current textures to contain only one basic shape. Some trial runs with mixtures of shapes produced better-looking textures, but these were not used in the main experiments. It would seem wise to use such mixtures in future experiments.

Suggestions for an improved texture-generation procedure

(1) Use elipses as the elementary splotches. The specifiable parameters would be

(a) major radius

(b) minor radius

(c) axis direction

This type of splotch would have smooth contours and would not have the problems of sharp points and straight edges that plague current textures.

(2) Allow all directions for the axis. This would solve the problem of direction quantization.

(3) Attribute height to the splotches and "illuminate" them from some particular lighting angle (sun angle). This would display height and shadow effects which would provide the edge effects necessary to distinguish adjacent, same-shade splotches.

(4) In accordance with the principle of associated qualities, attribute different gray level tendencies to different shapes. This will produce better associations than the uniform brightness distributions used currently and, at the same time, provide the texture with a greater variety of shape than the uni-shaped textures used so far.

REFERENCES

1. Darling, E. M. Jr.; and Joseph, R. D.: Pattern Recognition from Satellite Altitudes. IEEE, SSC-4, pp. 38-47, 1968.

APPENDIX A
DISCUSSION OF A GENERATOR FOR ARBITRARY TEXTURES

Ideally, one would like to have a set of elementary image operations that could, with appropriate combinations and sequencing, produce artificial textures simulating any desired real texture. This, however, seems to be an unachievable goal. In general, the complexity of the physical processes that produce real textures forces one to conclude that these processes themselves would have to be extensively simulated in order to artificially produce textures having a reasonable semblance to their real counterparts.

Consider the following:

(1) Geographic Features - These are produced by various eruptions and flows of viscous fluids which interact with each other and the atmosphere to produce mountains, rocky plains, and various erosion effects. To adequately simulate geographic textures, their physical process would probably have to be somehow simulated.

(2) Cloud Fields - Here the generating process is imbedded in a hydrodynamic system with consequent flow patterns and layers.

(3) Jungle - Here we have many complicated objects (bushes, trees, etc.) overlaying each other with various shadowing and translucency effects.

For all of the above, and in general, it would seem necessary to write a program for each class of real world textures one wished to simulate. The most generality that seems reasonably possible is to have a system that provides for easy simulation of various real world effects - hydrodynamic flow, gravity effects, various interactions - through a type of special language. Unless one has a very great interest in texture simulation, the construction of such a language system seems much more trouble than it is worth.

APPENDIX B
RASTER SCAN GENERATION OF TEXTURES

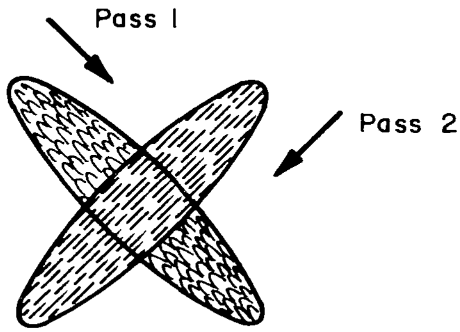
In reality, the splotches were not produced in the manner described, but rather in a series of raster scans that simulated this method by growing each splotch from its leftmost upper point. Such a raster scan mode makes accesses to semi-random memory (such as the disk) much more economical than the truely random accesses required by the original method. This raster scan generation is largely effective, but problems arise with overlayed splotches generated within the same pass. Consider splotches 1 and 2 in Figure 5a. It is very easy to have splotch 2 overlay splotch 1 because 2 is started later in the raster scan. To have splotch 1 overlay splotch 2, however, (as in Figure 5b) is more difficult, and, if done at all, requires a pseudo start and growth of splotch 2. This growth would have to be "underground" and invisible until the edges of splotch 1 were passed. This would require storing a double set of information, one about the visible splotch and one about the invisible. In general, an arbitrarily large set of these invisible splotches would have to be stored and this would negate the advantages of a simple raster scan. Therefore, the system as constructed stores information about the visible splotches only and restricts one to overlays from below or from the right (Figure 5a).

One partial way of overcoming this problem without greatly complicating things is illustrated in Figure 6. Here we have two long splotches intersecting, one coming from the upper left and one from the upper right. If they were to be generated in a single raster pass, one or the other would have to be aborted as in Figures 6b or 6c. This can be circumvented by generating the set of upper-left to lower-right splotches in one pass, and the set of upper-right to lower-left splotches in a second pass and merging the two passes (Figure 6a). Such multiple-pass generation is a compromise between pure raster generation and the placement of individual splotches as described in the body of the paper. In general one can get away with using a single pass for nondirectional and unidirectional textures, but has to use multiple passes for textures containing splotches of more than one direction.

In retrospect, the raster mode of generation is complicated and has a variety of restrictions. The author would not recommend it for use in general texture production, although it may suffice for particular varieties of specialized textures.

a. Easy b. Difficult

Figure 5.- Configurations of splotch overlays



a. Two Passes

b. One Pass c. One Pass

Figure 6.- Intersecting splotches

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